Cover Sheet ~~OFFICIAL USE ONLY (OUO)~~

OCRWM	DESIGN CALCULATION OR ANALYSIS COVER SHEET	1. QA: QA 2. Page 1 of 21

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The calculations contained in this document were developed by the Civil/Structural/Architectural (C/S/A) group of the Design and Engineering Department and are intended solely for the use of this department in its work regarding the structural design and analysis of surface facilities. Yucca Mountain Project personnel from the C/S/A group should be consulted before use of the calculations for purposes other than those stated herein or use by individuals other than authorized personnel in the Design and Engineering Department.

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Date 5/27/05

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Attachments	Total Number of Pages
Attachment A – Computer Files	1

RECORD OF REVISIONS

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Table of Contents

1.0 Purpose and Scope

This calculation documents the evaluation of potential schemes for the Aircraft Barrier for the 5000 Metric Tons of Heavy Metal (MTHM) Aging Areas. The evaluation investigates the following two barrier schemes:

a. A barrier made of light gauge metal or precast concrete confining panels and backfilled with soil or rock.
b. Earthen berm.

Preliminary calculations for each barrier type are developed in Section 7.0.

2.0 Quality Assurance

Table A-1 of the Q-List (BSC 2005a) identifies the Aircraft Barrier as an Important-to-Safety (ITS) structure. Consequently, the provisions of the Quality Assurance Requirements and Description (QARD) document (DOE 2004) apply to this calculation. This calculation was developed in accordance with the requirements of procedure AP-3.12Q.

3.0 Assumptions

3.1 Bounding Assumptions

3.1.1 It is assumed the barrier is 25'-0" high.

Rationale: this is a reasonable assumption for a preliminary evaluation of the aircraft barrier. Table A-II in Appendix A of the Nuclear Safety Design Basis (BSC 2005b) identifies that the barrier should be as high as the Spent Nuclear Fuel (SNF) and High Level Waste (HLW) casks. These casks will be about 20 ft. high. A 25 ft. high barrier is selected as conservative and bounding to ensure the generated by it, does not skim over the top of the barrier and strike a cask.

Where Used: Section 7.0

3.1.2 It is assumed the strike normal to the barrier.

Rationale: this is a reasonable, conservative assumption since this would result in all the impact energy acting in the horizontal, or weakest direction.

Where Used: Section 7.0

3.1.3 All impacts are assumed as

Rationale: this is a reasonable assumption since the impacts are of extremely short duration, the corresponding spring force effect is small, and the will tend to stay in contact with the target during and after the impact. There will be no rebound.

Where Used: Section 7.0

3.2 Assumptions Requiring Verification

3.2.1 One of the to be considered for evaluation is assumed to be a from the with an impact diameter of Diameter). and an impact velocity of . (TBV-7219 for velocity)

Rationale: this is a reasonable assumption given the similarity with the data for the other associated with the as provided in the Design Input section below; the engine weight and impact diameter are from Section 5.1.5, pg. 9, BSC (2001); the velocity has been communicated verbally and will be documented when the appropriate hazards analysis is completed.

Where Used: Sections 4.0 and 7.0

4.0 Design Input

The following , related to an impact by an will bound the potential rigid body penetrators from an impact of an

a. with an diameter and a speed of

b. with a diameter and a speed of

c. with a diameter and a speed of

d. itself with a impact diameter with the loading function shown on fig. A-5, pg. A-23 of C. W. Ma, et. al., (1990).

The data for a, b and d are from C. W. Ma, et. al. (1990); see Section A.6.1 for the weights and diameters of the and the ; see Figure A-3 for the weight of the see Section A.6.1 for the impact diameter for the ; and see Section A.2.1 for the velocity of these ; the data for "c" are from Assumption 3.2.1 above.

5.0 Evaluation Methodology

Table A-II of the Nuclear Safety Design Basis (BSC 2005b) also identifies the aircraft barrier must be designed to prevent breaching by an This also includes rigid body penetrators associated with the The two types of barriers are therefore evaluated using standard and special structural engineering hand techniques that are related to the design of structures for impact. Two types of failures are evaluated – a general failure where a section of the barrier is pushed out and collapses, somewhat like a punching shear failure in a concrete slab, and a local perforation of the barrier. These failures are illustrated on the next four figures:

FIGURE 5.1 - IMPACT OF GENERAL FAILURE OF A SECTION OF THE BARRIER, ELEVATION VIEW

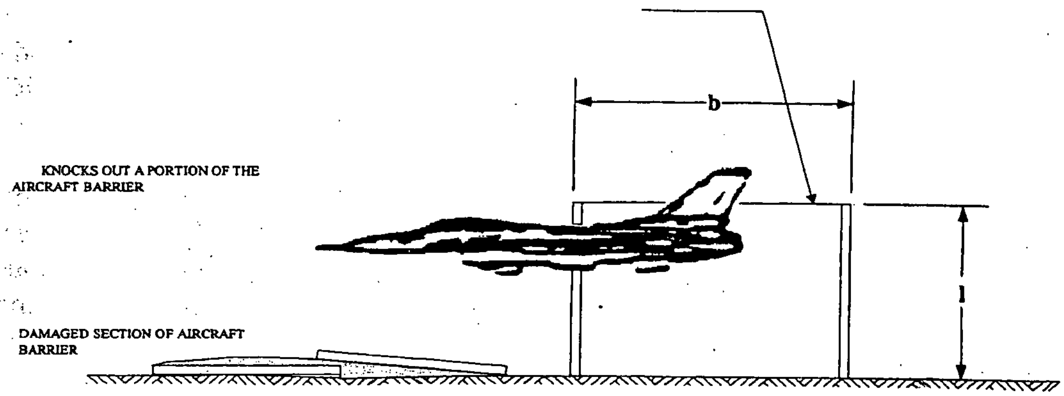


FIGURE 5.2 - IMPACT OF GENERAL FAILURE OF A SECTION OF THE AIRCRAFT BARRIER, PLAN VIEW

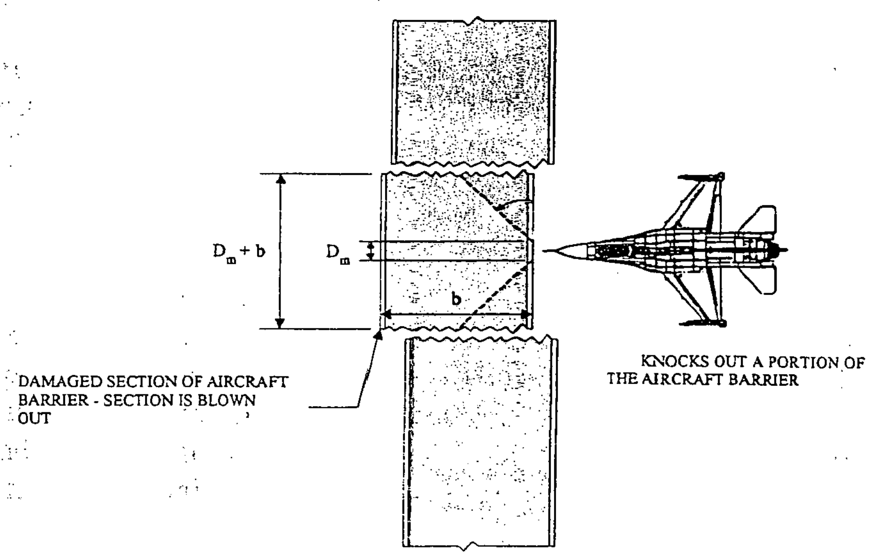


FIGURE 5.3 - IMPACT OF PENETRATION AND PERFORATION

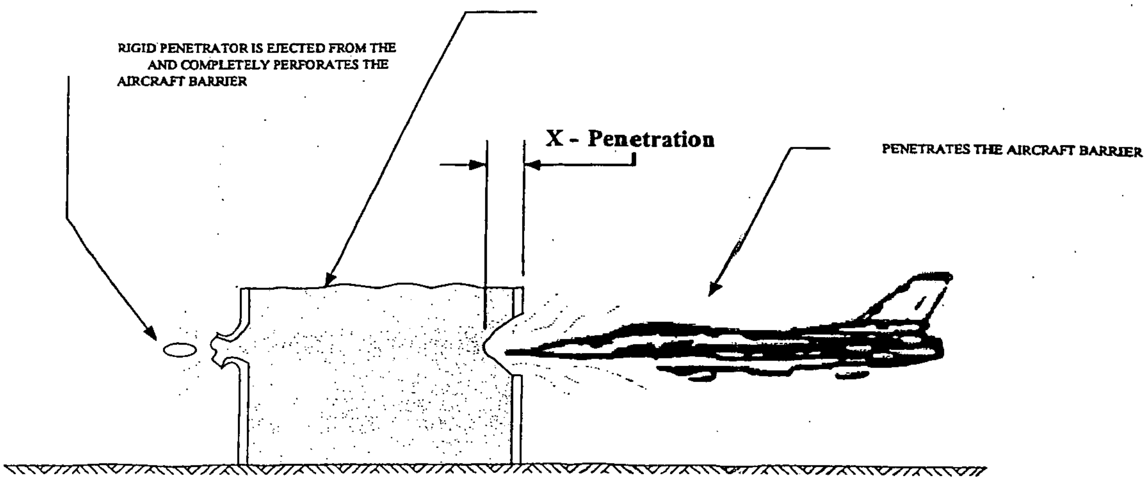
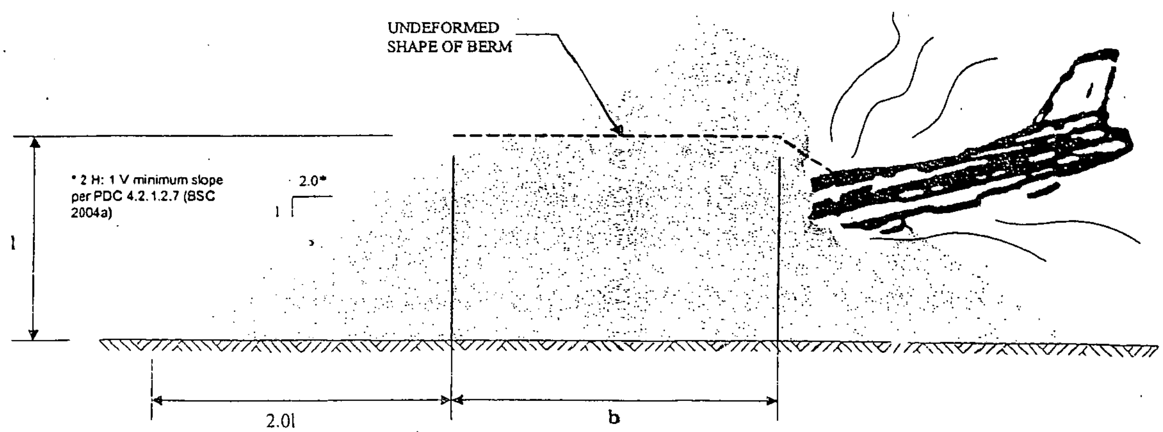


FIGURE 5.4 - IMPACT OF - PENETRATION OF



The general failure is evaluated by equating the kinetic energy of the impacting to the work required to move a section of the barrier. This allows the computation of the distance a section of the barrier that might move under a impact. If this distance is significant, say about the width of the barrier, then that is an indication that the barrier would fail and allow either the jet itself or a major rigid penetrator generated by the aircraft impact to "blow through" the barrier and impact the SNF and HLW casks. A wider barrier would therefore be required.

The local perforation failure (a completely passing through the barrier) is evaluated by using a soil penetration formula to compute the distance the would penetrate the soil mass represented by the aircraft barrier. If this distance is equal to or greater than the width of the barrier, then the barrier width would have to be increased to prevent perforation, otherwise the existing barrier width is acceptable.

5.1 Loads

The only loads that will be considered in this calculation are impacts from the listed above in Section 4.0, Design Input. Other loading conditions, i.e., dead, live, and those from natural phenomena (wind, seismic, precipitation), will be evaluated during detailed design.

5.2 Material Properties

The behavior of the barriers will be dominated by the properties of the soil used in constructing them. The confining light gauge metal or precast concrete panels are very thin compared to the width of the barrier. They will, therefore, make little contribution to the energy absorbing capabilities of the barrier and their presence will be ignored in this evaluation. Therefore, with respect to this evaluation, and the coefficient of friction between the and the upon which the barrier is founded are the critical properties.

It is desired to use the material that is removed during tunnel boring operations (called "tunnel muck") within the aircraft barrier structure. Table 10-3 of the Supplemental Soils Report (BSC 2004b) lists the densities of various materials that could be encountered during the tunnel boring operations. The densities ranged from 98 to 145 pcf. Consequently, the barriers are evaluated for a high-density soil of 150 pcf, a medium-density soil of 130 pcf, and a low-density soil of 100 pcf.

Table 11-2 of the Supplemental Soils Report (BSC 2004b) gives a coefficient of friction for alluvium as $\mu = 0.81$, but, because of the wide variation of soil and rock material that may be used, a value of $\mu = 0.6$ is used herein. Article 60.2 of K. Terzaghi, et. al. (1996) indicates that this is a minimum value for concrete against sand. Since the backfill material will be compacted against the alluvium, or engineered fills, both of which are granular materials (see articles 10.1.1.1 and 10.1.2.1 of the Supplemental Soils Report (BSC 2004b)), it will behave much like concrete on sand. The low-end value of μ given above is therefore appropriate for this evaluation.

6.0 Computer Software Documentation

The originator used the following computer programs to prepare this calculation; all the software used resides on a Personal Computer:

Program[2]	Version	Use	Software Tracking Number
Word[1]	97 SR-2	Word Processing	N/A – Commercial Off-the-Shelf Software
Mathcad[1]	11.2a	Calculations	N/A – Commercial Off-the-Shelf Software

Notes:

1. Microsoft Word and Mathcad are exempted from the qualification and documentation requirements of LP-SI.11Q-BSC, Software Management.

2. The software is operated on a PC system using the Windows 2000 operating system.

7.0 Calculations

Evaluation of Potential Aircraft Barrier Types:

Evaluate barriers made of light-gauge metal or pre-cast concrete panels backfilled with soil, tunnel muck, or other material by first investigating the potential for general structural failure. Treat the barrier as solid blocks that can slide.

Next, investigate perforation of the barriers by using a soil penetration formula to determine the minimum barrier thicknesses required to prevent complete perforation of the barrier. This will also be used to determine the minimum thickness required for an aircraft barrier constructed of a soil berm.

As discussed in Section 4.2 above, three fill, or soil, weight densities - 150 pcf, 130 pcf, and 100 pcf - are evaluated to ensure a range of possible densities are evaluated.

Per assumption 3.1.1, the barriers will be 25 ft. high; per assumption 3.1.2, the will strike normal to the face of the barriers; per assumption 3.1.3, the impacts will be analyzed as ; per assumption 3.2.1, the to be evaluated will include a with an impact diameter of and a impact speed of

Set origin of matrices to 1,1 instead of 0,0:

ORIGIN := 1

Define Units that are not standard in Mathcad:

$pcf := \frac{lbf}{ft^3}$ tons := 2000·lbf knots :=

Missile information - see Section 4.0 of this calculation:

$D_m := \begin{pmatrix} \\ \\ \end{pmatrix} \cdot in$ Diameters of

$V_{s_3} :=$ $V_{s_3} =$

$V_s := \begin{pmatrix} \\ \\ \end{pmatrix} \cdot mph$ $V_s = \begin{pmatrix} \\ \\ \end{pmatrix} \frac{ft}{sec}$ Velocities of

$M_m := \left(\quad \right) \cdot \frac{lbf}{g} \quad M_m = \quad lbf \cdot \frac{sec^2}{ft}$ Masses of

Evaluation of Potential Barriers:

Estimate required barrier width:

Investigate the possible width of barrier required by estimating the distance required to reduce the velocity to

$t_d :=$ Time of impulse. About 0.07 sec for the F-16. See the impulse plot in Fig. 7.2 of this calculation.

$X_0 := t_d \cdot \frac{V_{s_4}}{2}$ Based on formula 6.52, pg. 347, ASCE 58 (ASCE 1980).

$X_0 =$ Use at least a 25 ft. barrier.

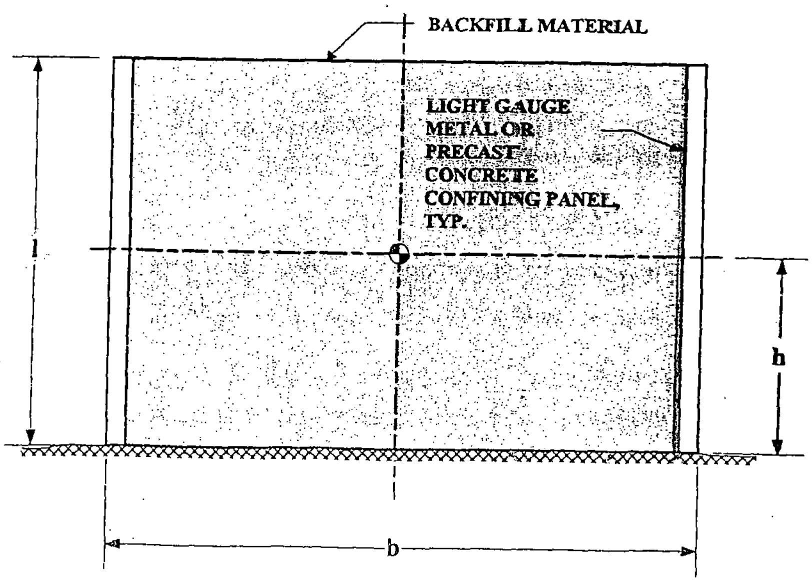
Evaluate the Potential for General and Local Failures:

See Figure ~~6~~ 7.1 below for the geometry of the aircraft barrier.

$b := 25 \cdot ft$ Width of barrier.

$l := 25 \cdot ft$ Height of barrier.

FIGURE 7.1 AIRCRAFT BARRIER, ELEVATION VIEW



$A := b \cdot l$ $A =$ Cross-sectional area of the Barrier.

$h := \frac{l}{2}$ Height to center of gravity of barrier element.

$h = 12.5 \text{ft}$

Determine target masses and impact energies:

$\rho_b := \left(\quad \right) \cdot \text{pcf}$ **Densities of barrier material.** [redacted]

$l := 1 .. 3$

$k := 1 .. 4$

Target mass (M_e) based on equation 3-16 (volume of target that interacts with the times the weight density divided the acceleration due to gravity, g), Chapter 3, Linderman, Rotz, and Yeh, 1974. Also see Fig. 5.2 of this calculation.

$\rho_b =$

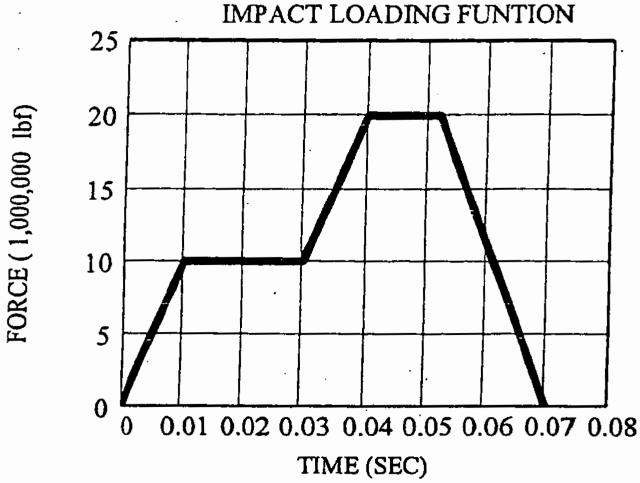
$$M_{e_{k,l}} := \left[\left(D_{m_k} + b \right) \cdot A \cdot \rho_{b_l} \right] \frac{1}{g} \quad M_e = \left(\quad \right) \text{lbf} \cdot \frac{\text{sec}^2}{\text{ft}}$$

Impact energies (EE_s) per equation 3-8, Section 3, Linderman, Rotz, and Yeh, 1974

$\rho_b =$

$$EE_{s_{k,l}} := \frac{\left(M_{m_k} \right)^2 \cdot \left(V_{s_k} \right)^2}{2 \cdot \left(M_{m_k} + M_{e_{k,l}} \right)} \quad EE_s = \left(\quad \right) \text{ft} \cdot \text{lbf}$$

Figure 7.2 - F-16 Loading Function



Loading Function - see Figure A-5 of C. W. Ma, et. al., 1990.

$F_1 := 10 \cdot 10^6 \cdot lbf \; F_2 := 20 \cdot 10^6 \cdot lbf$ Force function (see plot above).

$$\Pi := 0.5 \cdot F_1 \cdot (0.01 \cdot sec) + F_1 \cdot (0.04 - 0.01) \cdot sec \; ... \\ + 0.5 \left(F_2 - F_1\right) \cdot (0.04 - 0.03) \cdot sec + F_2 \cdot (0.052 - 0.04) \cdot sec \; ... \\ + 0.5 \cdot F_2 \cdot (0.07 - 0.052) \cdot sec$$

Impulse due to the Loading Function

$$\Pi = 8.2 \times 10^5 \, lbf \cdot sec$$

Recompute the impact energy for the F-16 missile using the above impulse.

$$EE_{s_{4,1}} := \frac{\left[\left(M_{m_4} + M_{e_{4,1}}\right) \cdot \Pi^2\right]}{2 \cdot \left(M_{e_{4,1}}\right)^2}$$

$EE_{s_{4,1}} =$ ft·lbf

impact energy per equation 3-14 (appropriate equation when forcing function is known), Section 3, Linderman, Rotz, and Yeh, 1974.

$l := 1 .. 3$

$i := 1 .. 4$

Masses of barrier. See Figures 4.2 and 6.1 in this calculation.

$\rho_b =$

$$M_{i,1} := \rho_{b_1} \cdot \frac{A \cdot \left(b + D_{m_i}\right)}{g} \qquad M = \left(\quad \right) lbf \cdot \frac{sec^2}{ft}$$

Weights of barrier.

$\rho_b =$

$$W := M \cdot g \quad W = \begin{pmatrix} 10^6 & 10^6 & 10^6 \\ 10^6 & 10^6 & 10^6 \\ 10^6 & 10^6 & 10^6 \\ 10^6 & 10^6 & 10^6 \end{pmatrix} lbf$$

$\rho_b =$

$W =$ tons

Evaluate Potential Sliding:

$\mu := 0.6$ See Section 5.2 of this calculation.

$\mu_e := \mu$

$i := 1..4 \quad l := 1..3$

Displacement due to sliding based on energy formula for sliding. Kinetic Energy due to missile impact = Work expended to move the Barrier a distance $\delta\delta$, i. e. $EE_s = (1/2)F\delta\delta = (1/2)\mu_e W\delta\delta$.

$\rho_b =$

$$\delta\delta_{i,1} := \frac{\left(2\cdot EE_{s_{i,1}}\right)}{\mu_e \cdot W_{i,1}} \qquad \delta\delta = \left(\quad \right) \text{ft} \quad \Big\} < b = 25\,\text{ft} \quad \text{OK}$$

Soil Penetration:

$S_1 := 1.07$ S for $\rho = 150$ pcf. See Table 3, pg. 811, Young (1969), for rock material from the Tonapah Test Range and the Nevada Test Site.

$$S_2 := 1.07 + \left(\frac{\rho_{b_1} - \rho_{b_2}}{\rho_{b_1} - \rho_{b_3}}\right)\cdot(4.4 - 1.07) \qquad S_2 =$$

S for $\rho =$. Weighted average value between rock and low density soil material based on values in Table 3, pg. 811, Young (1969)

$S_3 := 4.4$ S for $\rho = 100$ pcf. See Table 3, pg. 811, Young (1969), for Sand, silty, clayey, dense (desert alluvium) soil material from the Tonopah Test Range site.

$1 := 1..3$

$i := 1..4$

$N := \left(\quad \right)$ See Table 2, pg. 808, Young (1969), for various shapes of missiles

$$D_{mi_i} := \left(D_{m_i}\cdot in^{-1}\right) \qquad D_{mi} = \left(\quad \right)$$

Unitless vector of diameters for use in the penetration formula below.

$$A_{m_i} := \pi\cdot\frac{\left(D_{mi_i}\right)^2}{4} \qquad A_m = \left(\begin{matrix} \\ \cdot 10^3 \\ \\ \times 10^3 \end{matrix} \right)$$

Unitless vector of cross-sectional areas for use in the penetration formula below.

$$W_{m_i} := M_{m_i} \cdot g \cdot lbf^{-1} \quad W_m = \begin{pmatrix} 10^3 \\ \times 10^3 \\ \times 10^3 \\ \times 10^4 \end{pmatrix}$$

Unitless vector of the weights for use in the penetration formula below.

$i := 1 .. 4$

$$V_{si_i} := V_{s_i} \cdot \frac{sec}{ft} \quad V_{si} = \begin{pmatrix} \\ \\ \end{pmatrix}$$

Unitless vector of the velocities for use in the penetration formula below:

Penetration, X, for velocities based on Formula 17, pg. 812, Young (1969).

$X_{i,1} :=$

Penetration.

$\rho_b =$

$$X = \begin{pmatrix} \\ \\ \end{pmatrix} ft$$

$$\left.\right\} \begin{matrix} > & b = 25\,ft & NG \\ < & b = 25\,ft & OK \end{matrix}$$

NG for the 2000 lb with the fill. <u>Increase the barrier width to for a barrier backfilled with material.</u>

Check on Results:

Utilize the method of section 6.4.2.1.1 of ASCE 58 (ASCE 1980) for the evaluation of overall effects of soft missile impact by: (1) determining pseudo impulse times based on the calculation of penetration depths calculated above; (2) determining average impulses based on the calculation of impact energies on sht. 11 above; (3) calculating the forces associated with these impulses based on a rectangular force - time relationship; (4) using these forces, determine the penetration distance based on formula 6.50, pg. 347, ASCE 58 (ASCE 1980); if these distances determined in step (4) are consistent with those determined on sht. 15, then the designed barrier widths will be acceptable.

Calculate pseudo impulse times, impulse, and forces associated with the above displacements.

$l := 1 .. 3$

$i := 1 .. 4$

Impulse times:

$$tt_{d_{i,l}} := \frac{(2 \cdot X_{i,l})}{V_{s_i}}$$ Impulse time; see formula 6.52, pg. 347, ASCE 58 (ASCE 1980).

$\rho_b =$

$$tt_d = \left(\quad \right) \text{sec}$$

Impulses:

$$I_{i,l} := \sqrt{\frac{\left[2 \cdot \left(M_{e_{i,l}}\right)^2 \cdot EE_{s_{i,l}}\right]}{M_{m_i} + M_{e_{i,l}}}}$$ Impulse; based on formula 3-8 of Linderman, Rotz, and Yeh (1974) for impact energy; terms transposed to calculate impulse.

$\rho_b =$

$$I = \begin{pmatrix} \times 10^4 & \times 10^4 & \times 10^4 \\ \times 10^4 & \times 10^4 & \times 10^4 \\ \times 10^4 & \times 10^4 & \times 10^4 \\ 10^5 & 10^5 & 10^5 \end{pmatrix} \text{lbf} \cdot \text{sec}$$

Pseudo forces based on a rectangular Impulse curve:

$F_{i,1} := \dfrac{I_{i,1}}{tt_{d_{i,1}}}$ Pseudo forces based on definition of Impulse = Force x time.

$\rho_b =$

$$F = \begin{pmatrix} \times 10^6 & 10^6 & \times 10^5 \\ \times 10^6 & \times 10^6 & \times 10^6 \\ \times 10^6 & \times 10^6 & \times 10^5 \\ \times 10^7 & \times 10^7 & \times 10^7 \end{pmatrix} \text{lbf}$$

Penetration distances:

$X_{i,1} := \dfrac{\left[\left(\frac{1}{2}\right) \cdot M_{m_i} \cdot \left(V_{s_i}\right)^2\right]}{F_{i,1}}$ Penetration distance per formula 6.50 of ASCE 58 (ASCE 1980) with Mass, M_m, replacing W/g and terms transposed to calculate X.

$\rho_b =$

$$X = \begin{pmatrix} \\ \\ \\ \end{pmatrix} \text{ft}$$

OK since these distances are consistent with those calculated on the previous sheets. Use a 25 ft. wide barrier for and a 30 ft. wide barrier for material.

Determine the frontal pressures associated with the above calculated forces and missile geometries:

Cross-sectional areas based on missile impact diameters:

$$A_{mm_i} := \pi \cdot \frac{\left(D_{m_i}\right)^2}{4} \qquad A_{mm} = \left(\quad \right) ft^2$$

Frontal pressures:

$$\rho_b =$$

$$p_{i,1} := \frac{F_{i,1}}{A_{mm_i}} \qquad p = \left(\quad \right) psi$$

Sections A.6.1 and A.6.2 of Ma, et. al. (1990), gives frontal pressures of for the and for the Comparing these values to the very large magnitudes of frontal pressures calculated above indicates that the and its associated will when the aircraft impacts the barrier. The barrier widths determined in the preceding calculations the casks in the aging areas from aircraft impacts.

8.0 Conclusions & Recommendations

The calculations in Section 6.0 indicate that the aircraft barrier should be at least 25 ft. wide if the medium) or high density fill material is used. If dense material, s used, the barrier should be 30 ft. wide. The two barrier configurations are shown in Figures 7.1 and 7.2 below:

FIGURE 8.1 - AIRCRAFT BARRIER - BACKFILLED BARRIER W/ LIGHT GAUGE METAL OR PRECAST CONCRETE CONFINING PANELS OPTION, ELEVATION VIEW

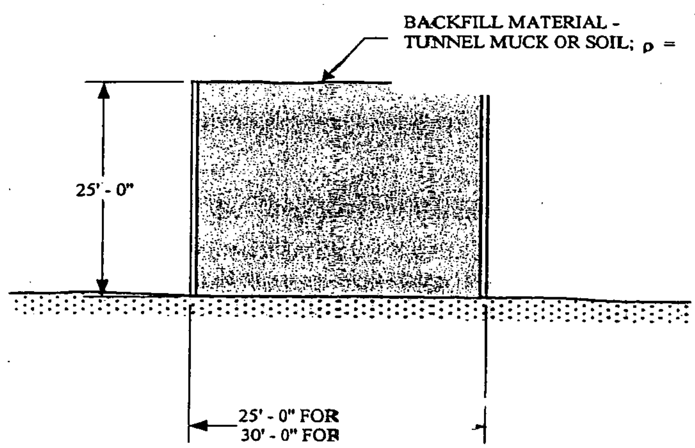
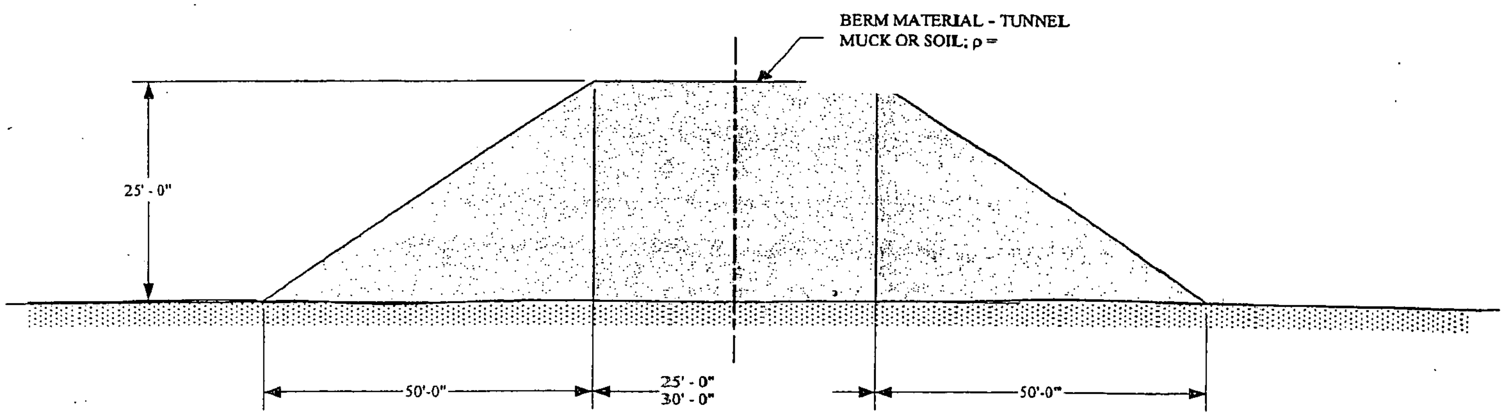


FIGURE 8.2 - AIRCRAFT BARRIER - BERM OPTION, ELEVATION VIEW



To keep construction costs and effort reasonable, it is recommended to utilize a 25 ft. high by 25 ft. wide barrier with light-gauge metal or precast concrete confining panels backfilled with a soil material or tunnel muck having a density of at compaction.

The design and analytical results are reasonable for their intended use considering the complex and dynamic nature of the loading the aircraft barrier could be exposed to. They are suitable for their intended use, namely the preliminary evaluation of an aircraft barrier for the Aging Area.

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Attachment A – Computer Files

Listed below and included in the attached CDs are the Word and Mathcad files that are pertinent to this calculation:

CALC Aircraft Barrier.doc
aircraft barrier.mcd